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ISSUE: Viewed from a national perspective, is the Space Shuttle likely to prove a cost-effective replacement for expendable launch vehicles?

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BACKGROUND: With the end of the Apollo program in sight in the late 1960s, the obvious question--"What next in Space?"--was decided in favor of an assault on the high costs of transportation. The announced goal was to reduce recurring costs by an order of magnitude or more, thereby removing what has been held to be the single most important obstacle to opening a cornicopia of opportunity for further technological exploitation of near space.

Conceptually, the challenge posed by this new goal was diametrically opposed to that inherent in Apollo. With Apollo, success was measured in terms of gaining and applying new technology while working against a widely publicized deadline in time; costs were of virtually no consequence. With the new venture, most of the essential technology was already at hand, requiring only to be scaled-up, and timing was of distinctly secondary interest. Instead, economic considerations were to be paramount. A total about-face in values had been proclaimed for the space establishment.

In 1971, the first funds were appropriated to develop a space Shuttle, the partially reuseable[1/] manned system which had emerged as the specific approach to be used in achieving the low-cost transportation objective. Through fiscal year 1978, U.S. Government investment in the Shuttle will have reached $9.6 billion[2/]. Another $7.7 billion will be required to complete development of the new Space Transportation System (STS), acquire a fleet of five orbiters, emplace an operational capability at two launch sites, and effect transition to Shuttle operations. In addition to the Shuttle proper, the STS includes a stable of new upper stages, and Spacelab, the new orbiting research station being developed by the European Space Agency. Spacelab will serve as the Shuttle's most important class of cargo, accounting for nearly half of the planned missions. The first regular Shuttle flights are now scheduled for 1980. Full-scale operations are anticipated by 1984 or 1985, at which time all use of heavy and medium-lift expendable vehicles will cease.

The NRO, DOD and NASA itself are all planning sizeable investments in back-up launch capabilities with expendable vehicles during the early transition phase of Shuttle operations. If the Shuttle achieves its targetted IOCs, this capability will not have to be used. If, on the other hand, the introduction of Shuttle operations is delayed much beyond six months, as now appears a roughly even-money proposition, additional expendable launch vehicles (ELVs) will be needed to bridge the gap. For national security payloads, where an assured launch capability is particularly important, it may well be deemed prudent to

1/ Of the Shuttle's three principal components, one, the Orbiter, is fully reuseable; a second, the external tank, is entirely consumed on each flight; and the third, a pair of solid rocket boosters, is reuseable on a limited basis (ten refills are hoped for).
2/ All cost estimates are expressed in dollars of projected FY 1979 purchasing power.

retain a back-up capability with proven ELVs well beyond mid-decade. This would provide insurance against the possibility of Shuttle groundings due to persistent technical anomalies. Not unknown to the expendable family of vehicles even after years of operational experience, such difficulties would be regarded much more seriously should they occur with the new manned system. Only minimum back-up insurance costing $0.9 billion is considered in the analysis which follows.

Economic Dimensions of the STS Venture

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The full costs to the Government of developing, introducing and operating the STS are shown in Table I on the following page. The estimates have been arrayed by obligating agency. Under its current pricing plans, NASA will redistribute about $2.0 billion of its obligations to other Government agencies. These accounting transactions will impose transfers of [redacted] from the NRO and [redacted] from the rest of DOD, leading to total Shuttle-related appropriations requirements [redacted] for the NRO and [redacted] for DOD with an offsetting reduction in NASA's appropriations needs. 25X1 25X1

Direct Government investment in the STS will total $15.8 billion. Investment in transitioning to Shuttle operations, including provision of a minimum ELV back-up capability, adds $2.4 billion for an investment total of $18.2 billion. Full amortization over the forcasted demand for 529 missions through FY 1992 (the National STS Traffic Model; see Table II, page 4) yields an average investment cost of $34.0 million per mission. 25X1

During the same period, total operating costs are estimated at $16.1 billion, or an average of $30.4 million per mission, for an overall total of $34.3 billion in Government outlays on behalf of the Space Transportation System--its development, its introduction and twelve-years-worth of operations.

A large share of the missions planned for the STS are expected to be sponsored by private corporations, foreign governments, and other non-U.S. Government organizations. NASA's pricing policies will recover about $3.5 billion from these participants (an average of $28 million for a typical mission, including charges for upper stages and other special services), reducing net U.S. Government STS outlays to $30.8 billion. It is worth noting that this class of customers, while claiming nearly one-fourth of the Shuttle's attentions (125 of 529 missions), will pay for only about ten percent of its costs ($3.5 billion out of $34.3 billion).

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This disparity arises from a policy of collecting no more than token repayments for the Government's investment costs. All told, including a modest allowance for the opportunity costs associated with devoting public resources to Shuttle development, this policy carries an implicit subsidization of special interest users in excess of $7 billion through FY 1992. NASA's charter provides a mandate to encourage domestic and international participation in cooperative space activities.

Although frequently overlooked in evaluations of Government programs, no resource allocation analysis can be complete, or entirely credible, until it has considered the question of opportunity costs. That is, the value which must be imputed to the privilege of having resources made available to pursue the particular ends of one productive activity at the expense of pursuing the alternative ends of some competing activity. Their low visibility to individual Government agencies in no way negates the reality of opportunity costs, or diminishes the importance of considering and comparing rates of return in weighing alternative resource allocations.

Ordinarily, a reasonable prospect of achieving an annual rate of return of twenty percent or more would be required in today's market to justify the long-term commitment of large amounts of new capital to a high-risk venture such as the Space Shuttle. In 1976, the overall average return realized by the 500 largest U.S. industrial corporations was 13.3 percent. Applying, instead, an ultra-conservative five percent[1/] discount rate to the resources consumed in STS development produces opportunity costs equal to $10.8 billion over the life of the venture. Inclusion of these costs leads to a total cost to the U.S. Government of $41.6 billion (net of special interest reinbursements), or an average of $103 million for each Government-sponsored mission.

In order to put the magnitude of the STS undertaking in better perspective, it might be noted that the largest transportation company in the U.S. in 1976 was United Airlines, which generated operating revenues on the order of $3 billion on assets of about $2 billion.[2/] By comparison, the level of activity being projected for the STS would command operating avenues in excess of $5 billion if priced to recover full economic costs. Assets of the STS will peak at nearly $14 billion. Thus by either standard, revenues or assets, the STS will represent the nation's largest single transportation effort by a very wide margin. The most efficient arrangement for managing the operational phase of this colossus poses an important Executive issue in itself.

1/ Typical of that now being realized by the rest of the U.S. Transportation industry, but grossly inadequate to attach new investment.
2/ Expressed in FY 1979 dollars.

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institutional incentive to price Shuttle services as low as it can in order to promote the major operational goal of a heavy, broadly based traffic volume. As the disparity which now exists between the real economic costs of Shuttle missions and the price NASA plans to charge for these missions becomes better appreciated, pressure to close the gap could become severe, and substantial price increases stemming from changes in the method of computation, unavoidable.

Projected savings in operating costs are further threatened by the cost uncertainty surrounding Shuttle operations. Unlike the cost estimates for ELVs, which are based on lengthy operational experience, the Shuttle estimates are projections arrived at by a conjectural process that is naturally biased on the low side (i.e., much more likely to err by omission than by over-inclusion). Real growth in the recurring costs of Shuttle operations might reasonably be expected to range between ten and thirty percent.

A second key area of uncertainty lies with the demand forecast, which projects a volume of payload traffic by the mid-1980s that is several times greater than today's. NASA believes this projection is conservative, inasmuch as half the anticipated volume will come from new payloads that cannot now be transported (i.e., Spacelab and research into the assembly of large structures). Still, the traffic model upon which Shuttle operating cost estimates have been based implies a near doubling in conventional payload traffic over the next several years. This may prove optimistic, especially if the current price is recomputed upwards to cover a greater portion of the Government's actual costs. Moreover, it is by no means certain that sufficient additional funding will be forthcoming to finance all of the new payloads NASA has incorporated in its mission model.

If greater demand materializes than the 529 missions now forecast, total costs will, of course, increase, but average costs will decline, thereby enhancing the economic attractiveness of the Shuttle venture. However, because of the shape of the Shuttle's operating cost curve, fewer missions will have a proportionately greater effect in the opposite direction. For example, a 200-mission increase in demand would be expected to reduce average operating costs by about 10-15 percent, to $26-27 million. But a 200-mission shortfall in demand would have twice as much impact; increasing average operating costs by 25-30 percent to as much as $40 million per mission.

The announced goal of NASA's pricing policy is to have recovered an exactly proportionate share of total operating from each user when the last projected Shuttle mission (i.e., the 529th) has been flown in FY 1992. The strategy is one of level real prices, with those sponsors who use the Shuttle early in the program, when average costs are still high, paying less than the marginal (i.e., "additional") costs incurred by their missions, and those who use it late, when economies of scale have brought marginal costs down, paying more than the costs directly incurred by their mission.

The principal purpose of this pricing strategy is to encourage early transition to Shuttle operations. Conceptually, there would be nothing severely wrong with it, if there was any real chance that it could be successfully implemented. Unfortunately, the prospect of this happening is extremely remote. The strategy is an inherently unstable one, in the best engineering sense of the word, since any unplanned deficiencies that arise from undercharging early users must be made up by offsetting overcharges levied on an ever shrinking pool of future users. If there is no departure from planning estimates, there is no problem; costs and prices would move onward along their respective paths to a neat confluence on the 529th flight.

But even comparatively minor deviations from these estimates will have drastic repercussions if not detected and acted upon immediately with appropriate price revisions. For example, the combination of ten percent cost growth and a 100-mission shortfall in demand would be offset by thirty percent price increase initiated in 1982, but would require a seventy percent increase if not acted upon until 1985, and could not be corrected at all later than 1986. Promptly and properly diagnosing cost or demand shifts of this magnitude will be an exceedingly difficult task, and reluctance to increase prices will retard reaction times. Finally, to the extent increased prices further curtail demand, they could serve to exacerbate the imbalances they are designed to redress.

What all of this means for the NFIB is that the estimates of operating savings from Shuttle usage should be viewed as extremely tentative. Such savings could evaporate entirely by the mid-1980s as a consequence of either revisions in NASA's pricing methodology, or the compounding affect of small errors in a few critical planning estimates.

<u>Alternatives to Full Transition to the Space Shuttle</u>

At present, the launch activities of the NRO account for about [redacted] (by payload weight) of the national space transportation effort. As Shuttle operations gain momentum, this share will steadily decline. Only [redacted] Shuttle flights will be claimed by intelligence payloads, which are projected to comprise only [redacted] of the total transported. What impact this diminished prominence will have on workaday launch operations is by no means clear. What is clear is that the effects of transition on the NFIB, however adverse, will not be

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25X1
25X1

the dominant consideration in STS-related decisions. Rather, the issue of Shuttle cost-effectiveness must be approached on a comprehensive, national basis.

Disregarding opportunity costs and the aforementioned caveats concerning the likelihood of achieving projected operating savings, and given that $9.6 billion has already been "sunk" in Shuttle development through 1978, on purely economic grounds alone the Shuttle still fails to emerge as a cost-effective replacement for payloads that might alternatively be transported via expendable vehicles.

This is indicated by the statistics displayed in Table 3, page 10, which compares the cost of flying the present National STS Traffic Model exclusively via the Shuttle as is now planned (Alternative 1-a), with three alternative courses: completing STS development, but retaining ELVs to transport national security payloads (Alternative 1-b); completing STS development, but restricting Shuttle usage to transporting those payloads (mainly Spacelab and large structure prototypes) that cannot be carried abroad ELVs (Alternative 1-c); and terminating Shuttle development altogether (Alternative 2). Generous allowances for termination costs have been incorporated in costing the options which involve lesser levels of STS activity.

The post-FY 1978 costs of flying the 529-mission demand forecast exclusively via the Shuttle is estimated at $24.6 billion: $16.0 billion for operations, and $8.6 billion to complete development and effect transition, including $0.9 billion invested in back-up ELVs sufficient to provide an assured launch capability for a Shuttle delay of about six months. A longer delay will require additional ELV funding.

If the NRO and DOD did not transition to Shuttle operations, but instead elected to fly the seventy-six missions now consigned to Shuttle with expendable vehicles (Alternative 1-b), about 190 ELVs would be needed in place of the Shuttle flights. The NRO would save [redacted] 25X1
under this option (including [redacted] in NASA charges), and DOD 25X1
would save about $0.2 billion 1/, but total costs would be very nearly the same on a national program level.2/ Investment savings to NRO and DOD from avoided transition costs, and to NASA from a one-orbiter reduction in the size of the Shuttle fleet (three orbiters would suffice to service the reduced demand under this option, plus an allowance of one for attrition) would be offset by the higher overall recurring costs of operating both ELVs and Shuttle concurrently.

1/ Net of $0.7 billion invested in ELV product improvement and completion of the Interim Upper Stage.
2/ The $0.1 billion difference between the estimated total cost for this option and that for all-Shuttle operations should not be considered significant.

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Table III

SUMMARY OF COSTS AND CAPABILITIES WITH ALTERNATIVE MODES OF SPACE TRANSPORTATION

	TRAFFIC VOLUME (Number of Shuttle-Equivalent Missions)					LAUNCH VEHICLE REQUIREMENTS a/		TRANSPORTATION COSTS b/ (Billions of FY79 Dollars)				
	via STS			via ELVs				STS				
ALTERNATIVE	Existing Capability	New Capability c/	Total STS	(Existing Capability)	Total Missions	Orbiters	ELVs	Invest.	Ops.	Total STS	ELVs	Total Costs
1. Complete STS development, and:												
a. Transition all transportation operations to STS as now planned.	253	276	529	...	529 d/	5	10-20 e/	7.7	16.0	23.7	0.9 f/	24.6
b. Use STS only for civil missions; retain ELVs for national security payloads.	177	276	353	76	529	4	200	5.5	11.5	17.0	7.5	24.5
c. Use STS only for payloads not compatible with ELVs, and only from KSC.	...	233	233	253	486	3	520 g/	4.1	8.2	11.9	14.1	26.4
2. Terminate STS development; limit space activities to missions compatible with ELVs.	...	...	...	253	253	...	520 g/	0.9	0.1	1.0 h/	14.3	15.3

a/ Includes allowance for attrition of one orbiter, ELV reserves based on historical reliabilities.
b/ Excludes sunk (i.e., FY78 and prior) costs. Costs in this category total $ 9.6 billion for STS.
c/ Spacelab and missions (35) researching the assembly of large structures in space.
d/ National STS Traffic Model (as of September 1976).
e/ Back-up vehicles in various stages of assembly.
f/ Subject to increase if initial STS operational capability is long delayed.
g/ Represents average annual launch rate two-thirds greater than present. Attendant economies of scale not considered in estimating operating costs.
h/ Estimated termination costs.

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The third option (Alternative 1-c), which envisions limiting Shuttle operations to transporting new payloads not compatible with ELVs, appears to be about $2 billion more costly than proceeding with the planned full transition. Moreover, this option assumes that work on configuring VAFB to STS would be terminated because of insufficient traffic in new payloads projected for WTR departures. Hence there would be no capability to fly the 43 missions that are so projected. Further investment savings generated from a two-ship reduction in orbiter procurement would also be negated by the greater overall operating costs which result from this roughly even division of traffic volume (totalling $21.6 billion, compared to $18.2 billion under Alternative 1-b and $16.0 billion for full STS operations).

In contrast to options 1-a and 1-b, which do not appear to be economically feasible alternatives to continuing with the current plan, Alternative 2, which postulates prompt termination of Shuttle development in favor of continued reliance on unmanned expendable vehicles, would realize very substantial savings at a national level. All of the civil and the national security payloads forecast for transportation via Shuttle (a traffic volume two-thirds greater than at present) could be transported via expendable vehicles at an estimated cost of $15.3 billion, or $9-10 billion less than the cost of completing and operating the Space Transportation System.

In return for these savings, a number of penalties difficult or impossible to quantify in dollar-and-cents terms would have to be accepted. Most directly, the new Spacelab and large structures research missions which can be performed effectively only with the Shuttle would be forfeit; and the expanded research opportunities they offer, indefinitely postponed. Inasmuch as the European Space Agency has been striving to develop Spacelab, which would be left stranded by a decision to terminate Shuttle, there is also a significant and immediate political dimension to this sacrifice. Although European investment in the STS has been minuscule compared to that of the U.S., it is sufficient to have made the venture a symbolic partnership.

Secondly, the nation would have to forego the intangible rewards of having a highly visible, American-led manned space program. Aside from reinforcing the image of U.S. technological excellence, such a program, featuring a payload selection process carried out on a cooperative international basis, will tend to promote other positive facets of the national character as well. Unlike the Apollo program, which has been criticized with some success as little more than an ostentatious and wasteful flaunting of national wealth, the Shuttle with its workaday regime is more likely to hold broad appeal as a truly beneficial step forward.

Finally, it should be noted that not all of the political considerations attendant Shuttle termination are international in scope. The prime contractor is North American Rockwell, with the largest piece of the development and production effort being carried-out at the company's facilities in Southern California. Although this work has already begun to taperoff, the same company will continue to play the major contractor role in supporting Shuttle operations. North American was also the prime contractor for the B-1 bomber, recently terminated by Presidential decision. Adverse reactions could also be expected from the grass roots American scientific community, wherein NASA has fostered high expectations for participation in Shuttle-transported experiments.

Breakeven Points for Shuttle Operations

The preceding cost effectiveness analysis has several limitations which merit notation. First, the methodology does not accommodate the economies of scale which would be expected to ensue from the much higher rate of ELV launches necessary to support the compatible portion of the demand forecast following a decision to terminate Shuttle. This means that the total cost for all-ELV operations (Alternative 2) is probably overstated by at least ten percent. The other two noteworthy shortcomings are: the limited (FY 1992) time horizon addressed in the analysis; and the omission of any allowance for payload savings. Both of these work against the case for Shuttle rather than for it, and consequently seem worthy of further discussion.

Since the original idea behind the Shuttle was the same as that underlying any investment decision, which is to spend a lot of money now in order to save some lesser amounts on a regular recurring basis in the future, the length of time over which these anticipated future savings are accumulated is critical. In the case of the Shuttle, there are sound arguments against extending the analysis much beyond the current mission model cut-off.1/ Nonetheless, because the projected difference in operating costs between Shuttle and ELVs falls well short of recovering investment during this time frame, it is useful to calculate just how long the Shuttle would have to remain in service for this break-even point to be attained.

1/Although NASA has estimated that each orbiter is capable of withstanding the ordinary wear and tear of as many as 500 missions, which theoretically would permit the STS to operate well into the twenty-first century (barring unforeseen accidental losses), it is extremely unlikely that the system will escape technical obsolescence long enough to come close to reaching this theoretical limit. It is a near certainty, of course, that measures will be proposed at some point in the 1980s to product-improve, or modernize, the initial Shuttle configuration. But any analysis postulating a prolonged service life based on such improvements would also have to consider their additional investment costs. Moreover, because the Shuttle design is fundamentally incapable of meeting the kinds of new transportation demands that are expected to arise in the 1990s, which will require transporting tens of thousands of tons for such projects as an economically viable space solar power station, there is bound to be a strong incentive to move on to much larger, more efficient vehicles as quickly as technology and budgets permit. Conceptual work on a new generation of very heavy lift vehicles is already well advanced.

If current projections of Shuttle operating costs prove accurate, and if the overall tempo of Shuttle flight activity does not slacken, transportation via Shuttle during the 1990s would be about half as costly as with ELVs. Beyond FY 1992, Shuttle usage would generate recurring annual savings in transportation costs of about $0.6 billion. Further recurring savings would be expected from changes in the design and fabrication of payloads, as a new generation emerged that had been tailored to the relaxed tolerances Shuttle's special capabilities for repair and retrieval will encourage.1/ Other savings in payload costs would be expected as a consequence of fewer enroute losses.2/

Recognizing that an unusually wide margin of uncertainty necessarily surrounds any attempt to quantify payload savings (especially those which accrue from evolutions in design philosophy), and that all such estimates should be treated with a healthy skepticism, $0.5 billion3/ annually would appear a generous allowance for this logically appealing, but intrinsically nebulous, consideration in computing the breakeven point for Shuttle operations.

Optimistically projecting operating savings of $5.7 billion in transporting ELV-compatible payloads through FY 1992, and $1.1 billion per year thereafter ($0.6 billion in transportation costs and $0.5 billion in payload costs), the STS would generate a three percent return on investment if each orbiter was used to the full limit of its 500-flight physical life expectancy. This breakeven point would be reached around fiscal year 2020.

Since neither this rate-of-return nor the payback period is satisfactory by any plausible standards, it is clear that the original Shuttle justification as a low-cost alternative to the continued use of expendable launch vehicles is no longer valid. Indeed, it is hard to believe that it ever really was.

On the other hand, since nothing can be done to retrieve the nearly $10 billion that has already been invested in Shuttle development, the more relevant questions pertain to the expectations of return on the $8.6 that remains to be spent in order to bring the program to fruition. If present estimates hold, the Shuttle could breakeven at a five percent rate of return on this additional investment if it remained operational through the turn of the century.

1/ Savings from this source are extremely difficult to project, and will probably never be known with precision even after the fact.
2/ An aborted ELV mission means a payload destroyed. If the Shuttle aborts, it will usually recover with its payloads intact. However, some payloads will still be lost in STS operations through upper stage malfunctions.
3/ Assuming today's payload costs are twice as great as today's transportation costs, and that a twenty-five percent reduction would be achieved with a new generation of payloads designed specifically for the Shuttle.

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Summary of Conclusions and Findings

• The Shuttle was originally conceived and justified primarily as a system that would lower the recurring costs of space transportation by an order of magnitude or more.

• It is now apparent that economies on this scale will not be achieved, and the debate has gradually shifted to whether Shuttle holds any cost-effectiveness advantage at all over expendable launch vehicles (ELVs).

• The NRO has estimated it will cost an additional [redacted] 25X1 through FY 1992 to transport intelligence payloads via Shuttle instead of ELVs. This estimate is based on NASA price quotes which are exceedingly vulnerable to criticisms of undercosting. Upward revisions in NASA prices could add another [redacted] to the NFIB. 25X1

• Intelligence payloads are projected to constitute only about [redacted] 25X1 percent of the cargo transported via the Shuttle. Shuttle-related decisions therefore transcend NFIB considerations. The cost-effectiveness issue can only be evaluated from a national perspective.

• Although both the NRO and DOD could save substantial sums by retaining ELVs, overall costs to the Government of dual ELV-Shuttle operations would be as great, or greater than, proceeding with full transition to Shuttle as is now planned. These mixed-systems alternatives do not appear feasible.

• The Shuttle is not a cost-effective alternative means of transportation for payloads which might otherwise be carried by ELVs. The forecast traffic in such payloads could be transported via ELVs for $9-10 billion less than the costs of completing and operating the Space Transportation System (STS).

• Substantive arguments for completing Shuttle development must be found in the new capabilities it offers, for research employing Spacelab and practice in assembling structures in space, and its political advantages, both in promoting the image of U.S. technological excellence and in fostering international cooperation under an American aegis.

• In strictly economic terms, the Shuttle has in retrospect been a poor investment. Under the most optimistic assumptions, it will yield no more than a three percent rate of return, and that will be achieved only if the entire orbiter fleet remains operational to FY 2020.

• Disregarding sunk costs, the Shuttle could under the same optimistic assumptions yield a five percent rate of return on the additional investment needed to complete development if the fleet remained fully operational through FY 2000.

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